FABRICATION OF A THERMOELECTRIC REFRIGERATOR

A project report submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

Submitted by

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Sangivalasa, Bheemunipatnam (Mandal), Visakhapatnam (Dist.)-531162

2019

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CERTIFICATE

This is to certify that the project entitled "**FABRICATION OF A THERMOELECTRIC REFRIGERATOR**" describes the bonafide work done by **S.TARUN (315126520200), P. LOKESWARARAO (315126520176), P.THOSHAN BABU (315126520178), S.SAI CHAITANYA (315126520207), S.ABDHUSH SHUKUUR (315126520203),** in partial fulfilment for the award of Degree in Bachelor OF ENGINEERING in MECHANICAL ENGINERRING under my supervision and guidance during the academic year 2018-2019.

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ACKNOWLEDGEMENT

We take this opportunity to express our deep and sincere thanks to our esteemed guide **Ms. B. Krishna Prafulla,** Assistant Professor, Mechanical Engineering Department, ANITS, a source of constant motivation and best critic, for her inspiring and infusing ideals in getting our project done successfully.

We present this report on **" FABRICATION OF A THERMOELECTRIC REFRIGERATOR"** in the partial fulfilment of the requirement for the award of BACHELOR OF TECHNOLOGY in MECHANICAL ENGINEERING.

We intend to express our thanks with sincere obedience to **Prof. T. Subrahmanyam,** Principal, ANITS and **Prof. B.Naga Raju,** Head of the department, Mechanical Engineering, ANITS for providing this opportunity.

Finally ,we are grateful to one and all who have contributed either directly or indirectly in the completion of the project.

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ABSTRACT

The main objective of this study is to design and fabrication on “portable thermoelectric refrigerator” for the people (e.g. deserts) living in remote areas where electricity is still not available. The refrigerator could be used to store perishable items and facilitate the transportation of medications as well as biological material that must be stored at low temperature to maintain effectiveness. The design of the thermoelectric refrigerator is based on the principles of a thermoelectric module (i.e. peltier effect) to create a hot side and cold side. The cold side of the thermoelectric module is utilized for refrigeration purposes; provide cooling to the refrigerator space. On the other hand, the heat from the hot side of the module is rejected to ambient surroundings by using heat sinks and fans.

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CHAPTER-1

INTRODUCTION

In most developed countries, the effort to create ‘green’ (environmentally friendly) technology is growing every day and people are paying additional money to purchase a product that will be less harmful to the environment in the long-term. In addition, customers across the globe are more than willing to save money every month on electricity bills due to energy-saving appliances.

Refrigeration is closely related to the demand for cooling foodstuffs and many other commodities as a normal part of commercial domestic life. However, we can’t have the convenience offered by refrigeration when we take outdoor activities, such as geological prospecting, archaeological study, etc.

1.1 REFRIGERATION TYPES

Solar refrigeration may be accomplished by using one of the following refrigeration systems:

- Vapor compression.
- Vapor absorption
- Thermoelectric refrigeration systems.

The first two systems need high and low pressure sides of a working fluid to complete the refrigeration cycle, and are somewhat difficult to be developed into a portable and light solar device used outside.

There are several merits offered by thermoelectric refrigerators over conventional refrigerators. First and foremost, a thermoelectric refrigerator does not produce chlorofluorocarbon (CFC), which has been one of the greatest causes of ozone depletion. In addition, the thermoelectric refrigerator can be constructed and manufactured within a range of sizes and weights, providing mobility and flexibility to clients. It does not use refrigerants without environment pollution and complicated transmission pipeline. It can only cool a special device or a specific area. The cooling box has small size and light weight, and it can save the construction area significantly. No mechanical rotation, so the cooling box is reliable and the maintenance is easy without noise and wear.

Unlike conventional refrigerators, there is no vibration or noise in the thermoelectric refrigerator because all parts are stationary and there is no mechanical motion during proper use. Moreover, the thermoelectric refrigerator is more reliable than the conventional refrigerator because of design simplicity. In addition, the single greatest motivating factor to commercialize the thermoelectric refrigerator is that the operational cost is almost zero since the refrigerator will use battery power instead of electric power. Finally, it offers the potential for greatly expanding medical facilities and research laboratories that need a cheap solution to preserve temperature-sensitive materials, especially in remote and poorer parts of the world. Overall, the thermoelectric refrigerator is a much cheaper, effective and environmentally friendly replacement to conventional refrigerators.

1.2 SCENARIO OF THERMOELECTRIC REFRIGERATION

With the rapid development of semiconductor industry, such as the heat transfer performance of thermoelectric materials has been greatly improved, and a series of new thermoelectric materials emerged. In recent years, the price of thermoelectric materials is declining, so the cost of semiconductor refrigeration production will decrease, and its performance has improved, which greatly contribute to the promotion of the technology of solar semiconductor refrigeration.

thermoelectric refrigerators are greatly needed in remote and rural areas for cold storage of vaccine and food, since the electric power supply is absent in these regions. Especially for people working outside, for example, mineral prospecting and road construction etc., they wish to keep their food fresh and their drink cold on sunny days.

1.3 SEMICONDUCTOR DEVICES

Semiconductor devices are electronic components that exploit the electronic properties of semiconductor materials, principally silicon, germanium, and gallium arsenide, as well as organic semiconductors. Semiconductor devices have replaced thermionic devices in most applications. They use electronic conduction in the solid state as opposed to the gaseous state or thermionic in a high vacuum. Semiconductor devices are manufactured both as single discrete devices and as integrated circuits (ICs), which consist of a number—from a few to billions—of devices manufactured and interconnected on a single semiconductor substrate, or wafer.

1.3.1 DOPING

In semiconductor production, doping intentionally introduces impurities into an extremely pure (also referred to as intrinsic) semiconductor for the purpose of modulating its electrical properties. The impurities are dependent upon the type of semiconductor. Lightly and moderately doped semiconductors are referred to as extrinsic. A semiconductor doped to such high levels that it acts more like a conductor than a semiconductor is referred to as degenerate. In the context of phosphors and scintillators, doping is better known as activation.

1.3.2 P-TYPE SEMICONDUCTOR

A p-type semiconductor (p for Positive) is obtained by carrying out a process of doping by adding a certain type of atoms (acceptors) to the semiconductor in order to increase the number of free charge carriers (in this case positive holes).

When the doping material is added, it takes away (accepts) weakly bound outer electrons from the semiconductor atoms. This type of doping agent is also known as an acceptor material and the vacancy left behind by the electron is known as a hole. When a sufficiently large number of acceptor atoms are added, the holes greatly outnumber thermal excited electrons. Thus, holes are the majority carriers, while electrons become minority carriers in p-type materials.

1.3.3 N-TYPE SEMICONDUCTOR

N-type semiconductors are a type of extrinsic semiconductor where the dopant atoms (donors) are capable of providing extra conduction electrons to the host material (e.g. phosphorus in silicon). This creates an excess of negative (n-type) electron charge carriers. In N- type majority charge carriers are electrons and minority charge carriers are holes.

1.3.4 P-N JUNCTION

A p–n junction is formed at the boundary between a p-type and n-type semiconductor created in a single crystal of semiconductor by doping, for example by ion implantation, diffusion of dopants, or by epitaxy (growing a layer of crystal doped with one type of dopant on top of a layer of crystal doped with another type of dopant). If two separate pieces of material were used, this would introduce a grain boundary between the semiconductors that severely inhibits its utility by scattering the electrons and holes

P–n junctions are elementary "building blocks" of most semiconductor electronic devices such as diodes, transistors, solar cells, LEDs, and integrated circuits; they are the active sites where the electronic action of the device takes place. For example, a common type of transistor, the bipolar junction transistor, consists of two p–n junctions in series, in the form n–p–n or p–n–p.

1.4 MATERIALS OF INTEREST

Strategies to improve thermoelectric include both advanced bulk materials and the use of low-dimensional systems. Such approaches to reduce lattice thermal conductivity fall under three general material types:

(1) Alloys: create point defects, vacancies, or rattling structures (heavy-ion species with large vibrational amplitudes contained within partially filled structural sites) to scatter phonons within the unit cell crystal.

(2) Complex crystals: separate the phonon-glass from the electron crystal using approaches similar to those for superconductors. The region responsible for electron transport would be an electron-crystal of a high-mobility semiconductor, while the phonon-glass would be ideal to house disordered structures and dopants without

disrupting the electron-crystal (analogous to the charge reservoir in high-T_c superconductors.

(3) Multiphase Nano composites: scatter phonons at the interfaces of nanostructured materials, be they mixed composites or thin film superlattices.

1.5. MATERIALS FOR THERMOELECTRIC DEVICE

1.5.1 BISMUTH CHALCOGENIDS

Materials such as Bi_2Te_3 and Bi_2Se_3 comprise some of the best performing room temperature thermoelectric with a temperature-independent thermoelectric effect, ZT, between 0.8 and 1.0. Nano structuring these materials to produce a layered super lattice structure of alternating Bi_2Te_3 and Bi_2Se_3 layers produces a device within which there is good electrical conductivity but perpendicular to which thermal conductivity is poor. The result is an enhanced ZT (approximately 2.4 at room temperature for p-type). Note that this high value has not entirely been independently confirmed.

Bismuth telluride and its solid solutions are good thermoelectric materials at room temperature and therefore suitable for refrigeration applications around 300 K. The Czochralski method has been used to grow single crystalline bismuth telluride compounds. These compounds are usually obtained with directional solidification from melt or powder metallurgy processes. Materials produced with these methods have lower efficiency than single crystalline ones due to the random orientation of crystal grains, but their mechanical properties are superior and the sensitivity to structural defects and impurities is lower due to high optimal carrier concentration.

OCCURENCE

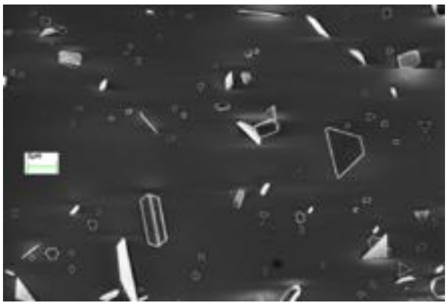

Fig 1.1: Image of small crystals of bismuth telluride

A scanning electron microscopy image of small crystals of bismuth telluride, in the same form as tellurobismuthite

The mineral form of Bi_2Te_3 is tellurobismuthite which is moderately rare. There are many natural bismuth tellurides of different stoichiometry, as well as compounds of the Bi-Te-S-(Se) system, like Bi_2Te_2S (tetradymite).

1.5.2 LEAD TELLURIDE

In 2008 Jeffrey Snyder and his colleagues have demonstrated that with thallium-doped lead telluride alloy (PbTe) it is possible to achieve ZT of 1.5 at 773 K. Later they reported ZT~1.4 at 750 K in sodium-doped PbTe, and ZT~1.8 at 850 K in sodium-doped $PbTe_{1-x}Se_x$ alloy. Snyder's group has determined that both thallium and sodium alter the electronic structure of the crystal increasing electric conductivity. They also claim that selenium increases electric conductivity and reduces thermal conductivity.

1.6 MATERIAL SELECTION CRITERIA

1.6.1 FIGURE OF MERIT

The figure-of-merit Z or ZT is the key Parameter that determines the efficiency of thermoelectric devices. There are more performance parameters that are usually not presented in standard specifications of commercial TE coolers, but that play a very important role in a module characterization. These parameters are the properties of material (thermal conductance (k), electrical resistance (R) and the Seebeck coefficient) combined as follows:

$$Z = \frac{\alpha^2}{kR}$$

The figure-of-merit Z has a unit of inverse Kelvin and therefore, often appears as a dimensionless product with an absolute temperature. To maximize the thermoelectric figure of merit (zT) of a material, a large thermopower (absolute value of the Seebeck coeffcient), high electrical conductivity, and low thermal conductivity are required.

The best ZT materials are found in heavily-doped semiconductors. Insulators have poor electrical conductivity that leads to a low thermoelectric effect. Metals are also poor thermoelectric materials because of their low Seebeck coefficient and high thermal conductivity. . It is estimated that materials with ZT>3 are required to replace traditional coolers in most applications.

The figure of merit can be improved through the independent adjustment of these properties.

1.6.2 THERMAL CONDUCTIVITY

$\kappa = \kappa_{electron} + \kappa_{phonon}$

According to the Wiedemann–Franz law, the higher the electrical conductivity, the higher $\kappa_{electron}$ becomes. Therefore, it is necessary to minimize κ_{phonon}. In semiconductors, $\kappa_{electron} < \kappa_{phonon}$, so it is easier to decouple κ and σ in a semiconductor through engineering κ_{phonon}.

1.6.3 ELECTRICAL CONDUCTIVITY

Metals are typically good electrical conductors, but the higher the temperature, the lower the conductivity, given by the equation for electrical conductivity:

$\sigma_{metal} = ne^2\tau/m$

- n is carrier density
- e is electron charge
- τ is electron lifetime
- m is mass

As temperature increases, τ decreases, thereby decreasing σ_{metal}. By contrast, electrical conductivity in semiconductors correlates positively with temperature.

$\sigma_{semiconductor} = ne\mu$

- n is carrier density

- e is electron charge
- μ is carrier mobility

Carrier mobility decreases with increasing temperature, but carrier density increases faster with increasing temperature, resulting in increasing $\sigma_{semiconductor}$.

CHAPTER-2

LITERATURE REVIEW

The true nature of Peltier effect was made clear by Emil Lenz in 1838, Lenz demonstrated that water could be frozen when placed on a bismuth-antimony junction by passage of an electric current through the junction. He also observed that if the current was reversed the ice could be melted. In 1909 and 1911 Altenkirch give the basic theory of thermoelectrics. Rowe [1] work explained those thermoelectric cooling materials needed to have high Seebeck coefficients, good electrical conductivity to minimize Joule heating, and low thermal conductivity to reduce heat transfer from junctions to junctions. In 1949 loffe developed theory of semiconductors thermoelements and in 1954 Goldsmid and Douglas demonstrated that cooling from ordinary ambient temperatures down to below 0oC was possible. Shortly after the development of practical semiconductors in 1950's, Bismuth Telluride began to be the primary material used in the thermoelectric cooling.

Dai et al. [2] have designed and developed a thermoelectric refrigeration system powered by solar cells generated DC voltage and carried out experimental investigation and analysis. They developed a prototype which consists of a thermoelectric module, array of solar cell, controller, storage battery and rectifier. The system with solar cells and thermoelectric refrigerator is used for outside purpose in daytime and system with storage battery, AC rectifier and TER is used in night time when AC power is available. Experimental analysis on the unit was conducted mainly under sunshine conditions. The studied refrigerator can maintain the temperature in refrigerated space at 5–10oC, and has a COP about 0.3 under given conditions

Min et al. [3] developed a number of prototype thermoelectric domestic-refrigerators with different heat exchanger combination and evaluated their cooling performances in terms of the COP, heat pumping capacity, cooling down rate and temperature stability. The COP of a thermoelectric refrigerator is found to be 0.3-0.5 for a typical operating temperature of 5^{o}C with ambient at 25^{o}C. The potential improvement in the cooling performance of a thermoelectric refrigerator is also investigated employing a realistic model, with experimental data obtained from this work. The results show that an increase in its COP is possible through improvements in module contact resistances, thermal interfaces and the effectiveness of heat exchangers.

Wahab et al. [4] designed and developed an affordable thermoelectric refrigerator powered by solar cells generated DC voltage for the desert people living in Oman where electricity is not available. In this study the researchers used 10 nos. of thermoelectric module in design of refrigerator. The finned surface (heat sink) was used to enhance and increase the rate of heat transfer from the hot surface of thermoelectric module. Cooling fan was used to reject the heat from the hot side of module to ambient surroundings. The experimental data collected from running one thermoelectric module indicate that it is possible to achieve temperature difference upto 26.6°C at current 2.5 A and voltage 3.7 V. The coefficient of performance of the refrigerator was calculated and found to be about 0.16.

An experimental study on cooling performance of a developed combined Solar Thermoelectric- Adsorption cooling system has been carried out by Abdullah et al. [5]. They developed a novel solar thermoelectric-adsorption cooling system and tested at eight different days. Cooling is produced via the Peltier effect during the day, by means of thermoelectric elements, and through adsorption process at night. They evaluate the coefficient of performance values by using derived equations, the average COP values of the overall system were found ~ 0.131 (adsorption) and ~ 0.152 (thermoelectric), respectively

Putra [6] designed, manufactured and tested a portable vaccine carrier box employing thermoelectric module and heat pipe. The position of heat pipe as a heat sink on the hot side of the TEM enhanced the cooling performance. The minimum temperature in the vaccine carrier cabin reached -10oC, which shows that vaccine carrier can store the vaccine at desired temperature.

Adeyanju et al. [7] carried out a theoretical and experimental analysis of a thermoelectric beverage chiller. Comparison were also made between the thermoelectric beverage chiller’s cooling time with cooling times obtained from the freezer space and cold space of a household refrigerator. The result shows that for the refrigerator freezer space, the temperature of the water decreased linearly with increasing time and for thermoelectric beverage chiller the temperature of the water decreased exponentially with increasing time.

Lertsatitthanakorn et al. [8] evaluated the cooling performance and thermal comfort of a thermoelectric ceiling cooling panel (TE-CCP) system composed of 36 TEM. The cold side of the TEM was fixed to an aluminum ceiling panel to cool a test chamber of 4.5 m3 volume, while a copper heat exchanger with circulating cooling water at the hot side of the TE modules was used for heat release. Thermal acceptability assessment was performed to find out whether the indoor environment met the ASHRAE Standard-55’s 80% acceptability criteria. The standard was met with the TE-CCP system operating at 1 A of current flow with a corresponding cooling capacity of 201.6 W, which gives the COP of 0.82 with an average indoor temperature of 27oC and 0.8 m/s indoor air velocity.

Gillott et al. [9] conducted an experimental investigation of thermoelectric cooling devices for small-scale space conditioning applications in buildings. They performed a theoretical study to find the optimum operating conditions, which were then applied in the laboratory testing work. A TEC unit was assembled and tested under laboratory conditions. Eight pieces of Ultra TEC were shown to generate up to 220W of cooling effect with a COP of 0.46 under the input current of 4.8A for each module.

Bansal et al. [10] conducted a detail study on energy efficiency and cost-effectiveness for vapour compression, thermoelectric and absorption refrigeration of similar capacity (about 50 liter). The investigated result show that vapour compression refrigerator was the most energy efficient (with a COP of 2.59) followed by thermoelectric (COP of 0.69) and absorption refrigerator (COP of 0.47). The Cost analysis results show that the total purchasing and operating costs over the life of the systems was the lowest for the vapour-compression unit at NZ$506, followed by the thermoelectric ($1381.2) and the absorption refrigerator ($1387.4). The researchers finally concluded that the VC refrigerator was the most energy efficient and cheaper unit followed by the thermoelectric and the absorption refrigeration.

CHAPTER-3

THERMOELECRIC REFRIGERATION

French watchmaker, **Jean Charles Athanase Peltier**, discovered thermoelectric cooling effect, also known as Peltier cooling effect, in 1834. Peltier discovered that the passage of a current through a junction formed by two dissimilar conductors caused a temperature change. However, Peltier failed to understand this physics phenomenon, and his explanation was that the weak current doesn't obey Ohm's law. Peltier effect was made clear in 1838 by Emil Lenz,. Lenz demonstrated that water could be frozen when placed on a bismuth-antimony junction by passage of an electric current through the junction. He also observed that if the current was reversed the ice could be melted.

In 1909 and 1911 another scientist **Altenkirch** derived the basic theory of thermoelectric. His work pointed out that thermoelectric cooling materials needed to have high Seebeck coefficients, good electrical conductivity to minimize Joule heating, and low thermal conductivity to reduce heat transfer from junctions to junctions. Shortly after the development of practical semiconductors in 1950's, Bismuth telluride began to be the primary material used in the thermoelectric cooling.

3.1 THERMOELECTRIC EFFECTS

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice-versa. A thermoelectric device creates a voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference. At the atomic scale, an applied temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side, similar to a classical gas that expands when heated hence inducing a thermal current.

The term "thermoelectric effect" encompasses three separately identified effects: Seebeck effect, Peltier effect and Thomson effect. Joule heating is the heat that is generated whenever a voltage is applied across a resistive material is related though it is not generally termed a thermoelectric effect. The Peltier–Seebeck and Thomson effects are thermodynamically reversible whereas Joule heating is not.

3.1.1 SEEBECK EFFECT

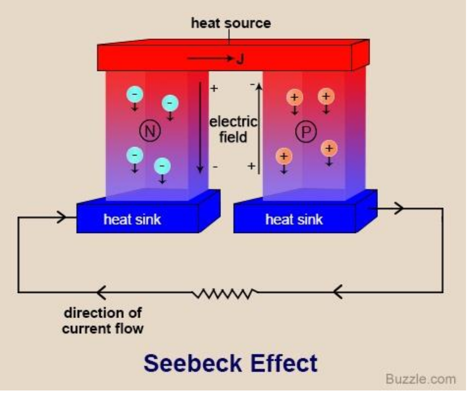

Fig 3.1 Circuit of Seebeck effect. A and B are two different metals.

The Seebeck effect was discovered by Thomas Seebeck in 1821. It is associated with the generation of a voltage along a conductor subject to a temperature gradient $\Delta T=T_2-T_1$ .If a temperature gradient applies to a conductor, an electromotive force $\Delta V=V_2-V_1$ will occur between the hot and cold ends due to charge carrier diffusion and phonon drag.

3.1.2 PELTIER EFFECT

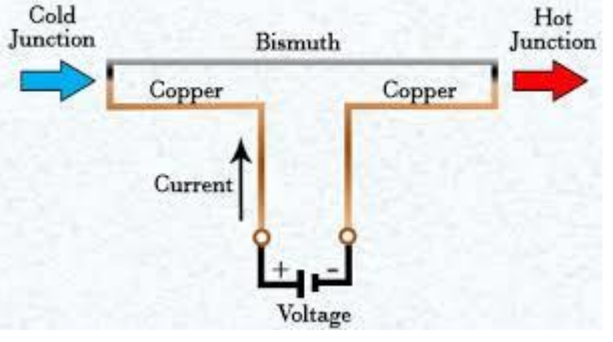

Fig 3.2: Circuit of Peltier effect. 1and 2 are two different metals.

When two different materials are joined together to form a loop, there will be an abrupt change in heat flow at the junctions because the two materials have different Peltier coefficients.

The Peltier heat $\dot{Q}$ absorbed by the lower junction per unit time is equal to

$$\dot{Q} = \Pi_{AB} I = (\Pi_B - \Pi_A) I,$$

Where Π_{AB} is the Peltier coefficient for the thermocouple composed of materials A and B and Π_A (Π_B) is the Peltier coefficient of material A (B). Π varies with the material's temperature and its specific composition.

The Peltier coefficients represent how much heat current is carried per unit charge through a given material. Since charge current must be continuous across a junction, the associated heat flow will develop a discontinuity if Π_A and Π_B are different. Depending on the magnitude of the current, heat must accumulate or deplete at the junction due to a non-zero divergence there caused by the carriers attempting to return to the equilibrium that existed before the current was applied by transferring energy from one connector to another.

3.1.3THOMSON EFFECT

The Thomson effect was predicted and subsequently observed by Lord Kelvin in 1851. It describes the heating or cooling of a current-carrying conductor with a temperature gradient.

Any current-carrying conductor with a temperature difference between two points either absorbs or emits heat, depending on the material. If a current density J is passed through a homogeneous conductor, the heat production q per unit volume is:

$$q = \rho J^2 - \mu J \frac{dT}{dx}$$

Where ρ is the resistivity of the material, dT/dx is the temperature gradient along the wire and μ is the Thomson coefficient. Lead is commonly stated to have a Thomson coefficient of zero.

3.2 COMPONENTS

The main components of the thermoelectric refrigerator include

- Thermoelectric module.
- Battery

- Heat sink (or finned surface)
- Cooling fan.
- Thermal Grease
- Cooling box
- Play wood pads and glass wool
- Digital Thermometer
- Voltmeter
- Ammeter

3.3 THERMOELECTRIC MODULE

A thermoelectric (TE) module is a semiconductor-based electronic component that functions as a small heat pump. The basic principle on which it works is thermoelectric effect.

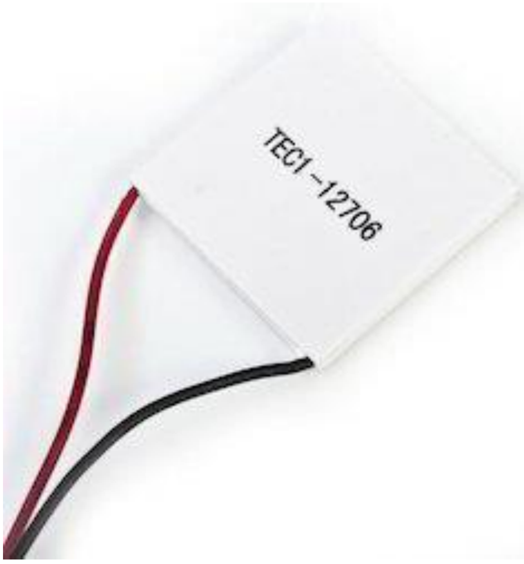

Fig 3.3: Thermoelectric module

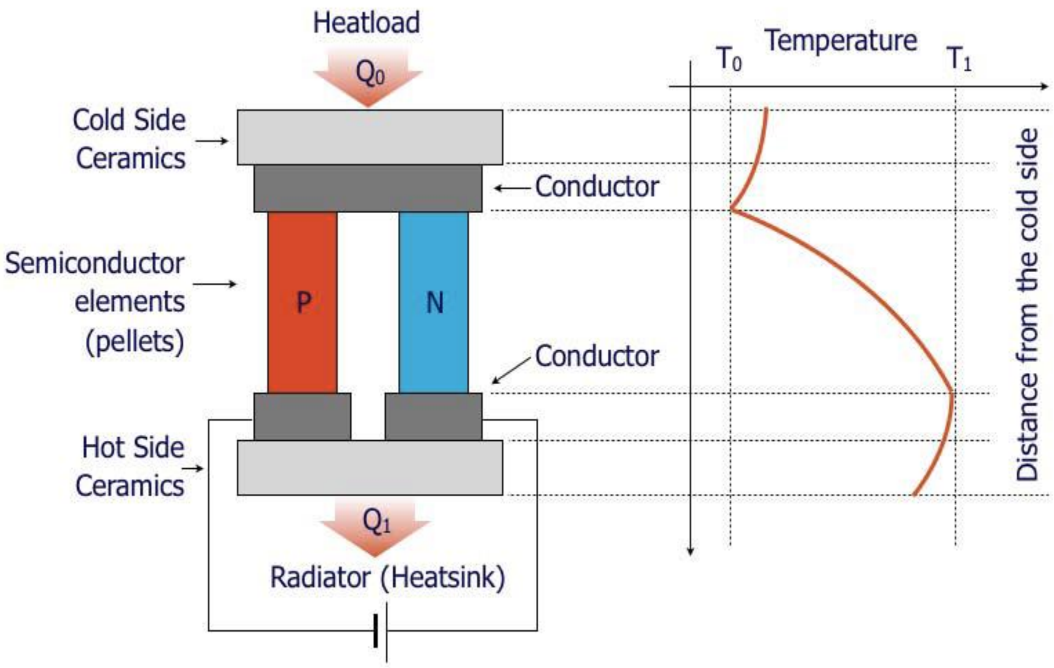

Fig 3.4: Simplified Scheme of TE Module

By applying a low voltage DC power to a TE module, heat will be moved through the module from one side to the other. One module face, will be cooled while the opposite face is simultaneously heated. It is important to note that this phenomenon may be reversed whereby a change in the polarity of the applied DC voltage will cause heat to be moved in the opposite direction. A thermoelectric module may be used for both heating and cooling.

The thermoelectric module consists of a number of N-type and P-type semiconductor thermo elements connected in series by copper strips and sandwiched between two electrically insulating, but thermally conducting, ceramic plates. The only limitation of the module is that it must only be operated under a certain temperature difference between the cold and hot sides depending on the electrical input and the thermoelectric material properties.

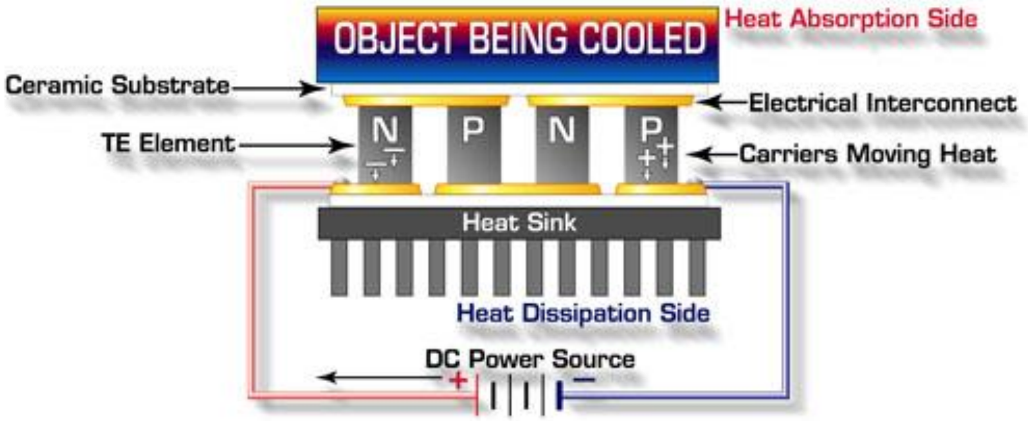

Fig 3.5: Doped module

Cooling capacity (heat actively pumped through the thermoelectric module) is proportional to the magnitude of the applied DC electric current and the thermal conditions on each side of the module. By varying the input current from zero to maximum, it is possible to regulate the heat flow and control the surface temperature.

3.3.1 BISMUTH TELLURIDE SEMICONDUCTOR MATERIALS

Bismuth telluride

Bismuth telluride (Bi_2Te_3) is a gray powder that is a compound of bismuth and tellurium also known as bismuth telluride. It is a semiconductor which, when alloyed with antimony or selenium is an efficient thermoelectric material for refrigeration or portable power generation. Topologically protected surface states have been observed in Bismuth telluride.

Table 1: Properties of Bismuth telluride

Molecular Formula	**Bi_2Te_3**
Molecular mass	**800.761 g/mol**
Appearance	**grey powder**
Density	**7.7 g/cm^3**
Melting point	**585^{0}C**
Surface Crystal Structure 3m,	**Trigonal, hR15, Space Group = R- No.166**

Bismuth telluride is a narrow gap layered semiconductor with a trigonal unit cell. The valence and conduction band structure can be described as a many-ellipsoidal model with 6 constant-energy ellipsoids that are centered on the reflection planes. Bi_2Te_3 cleaves easily along the trigonal axis due to Van der Waals bonding between neighboring tellurium atoms. Due to this, bismuth telluride based material that is used for power generation or cooling applications must be polycrystalline. Furthermore, the Seebeck coefficient of bulk Bi_2Te_3 becomes compensated around room temperature, forcing the materials used in power generation devices to be an alloy of bismuth, antimony, tellurium, and selenium.

In one such instance n-type bismuth telluride was shown to have an improved Seebeck coefficient (voltage per unit temperature difference) of −287 µV/K at 54 Celsius, However, one must realize that Seebeck Coefficient and electrical conductivity have a tradeoff; a higher Seebeck coefficient results in decreased carrier concentration and decreased electrical conductivity.

Bismuth telluride has

i) High electrical conductivity of 1.1×10^5 S·m/m^2

ii) Very low lattice thermal conductivity of 1.20 W/(m^2·K), similar to ordinary glass.

3.4 BATTERY

Since solar energy is not continuous, in order to ensure that the refrigerator can be worked continuously at night and cloudy days, the system is equipped with battery and it is also equipped with a controller which has the function of protecting battery to avoid over charge and over discharge. Electrical energy is converted into chemical energy and is stored in battery.

The role of battery is storage energy when solar cell converted and to keep power supply at any time to load. The battery used in solar power generation system has some basic requirements, such as low self-discharge rates, long life, and deep discharge ability, charging efficiency, less maintenance or maintenance-free, wide working temperature range and low prices. Battery used in this paper can achieve with the discharge depth of about 80% of the deep discharge maintenance-free battery. It should consider the output voltage and capacity. Its output voltage should match with the controller in the system and its capacity should insure the refrigerator working normally for some time when the system at no sunlight circumstances.

Fig 3.6: Battery

SPECIFICATIONS OF THE BATTERY

Voltage: 12 volts

Current: 7.2 amperes

3.5 HEAT SINK

In electronic systems, a heat sink is a passive component that cools a device by dissipating heat into the surrounding air. Heat sinks are used to cool electronic components such as high-power semiconductor devices, and optoelectronic devices such as higher-power lasers and light emitting diodes (LEDs). Heat sinks are heat exchangers such as those used in refrigeration and air conditioning systems, or the radiator in an automobile.

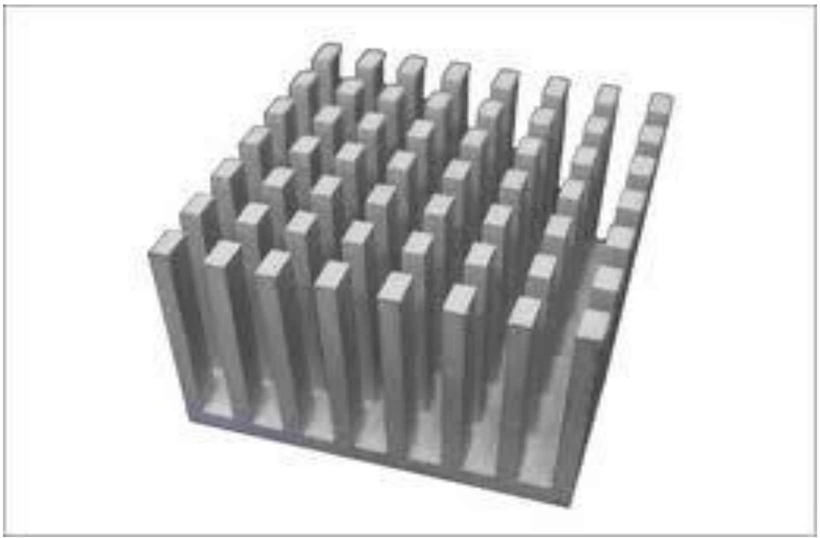

Fig3.7: Heat sink

A heat sink is designed to increase the surface area in contact with the cooling fluid surrounding it, such as the air. Approach air velocity, choice of material, fin (or other protrusion) design and surface treatment are some of the factors which affect the thermal performance of a heat sink. Heat sinks are used to cool computer central processing units or graphics processors. Heat sink attachment methods and thermal interface materials also affect the eventual die temperature of the integrated circuit. Thermal adhesive or thermal grease fills the air gap between the heat sink and device to improve its thermal performance. Theoretical, experimental and numerical methods can be used to determine a heat sink's thermal performance.

3.5.1 BASIC HEAT SINK HEAT TRANSFER PRINCIPLE

A heat sink is an object that transfers thermal energy from a higher temperature to a lower temperature fluid medium. The fluid medium is frequently air, but can also be water or in the case of heat exchangers, refrigerants and oil. If the fluid medium is water, the 'heat sink' is frequently called a cold plate. In thermodynamics a heat sink is a heat reservoir that can absorb an arbitrary amount of heat without significantly changing temperature. Practical heat sinks for electronic devices must have a temperature higher than the surroundings to transfer heat by convection, radiation, and conduction.

Consider Fourier's law of heat conduction. Fourier's law of heat conduction, simplified to a one-dimensional form in the x-direction, shows that when there is a temperature gradient in a body, heat will be transferred from the higher temperature region to the lower temperature region. The rate at which heat is transferred by conduction, q_k, is proportional to the product of the temperature gradient and the cross-sectional area through which heat is transferred.

$$q_k = -kA\frac{dT}{dx}$$

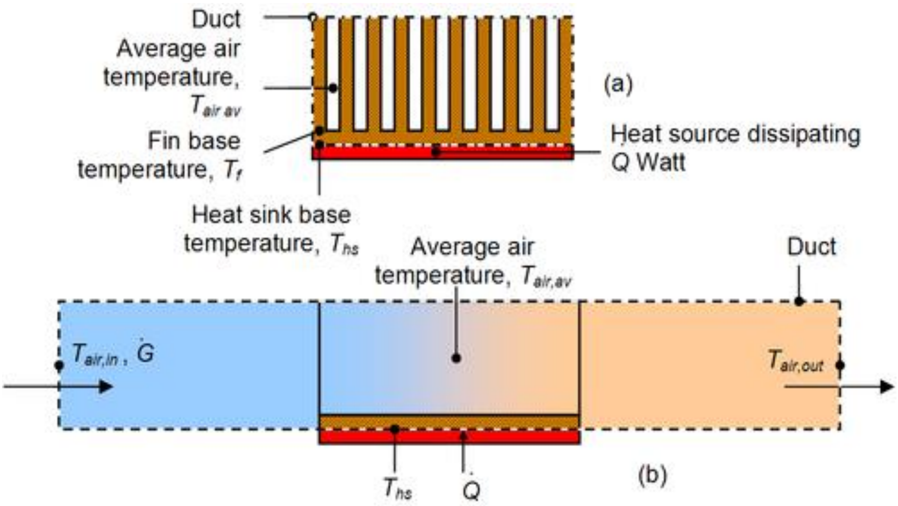

Figure3.8: Sketch of a heat sink

Consider a heat sink in a duct, where air flows through the duct, as shown in Figure 3.11. It is assumed that the heat sink base is higher in temperature than the air. Applying the conservation of energy, for steady-state conditions, and Newton’s law of cooling to the temperature nodes shown in Figure 2 gives the following set of equations.

$$\dot{Q} = \dot{m}c_{p,in}(T_{air,out} - T_{air,in}) \quad (1)$$

$$\dot{Q} = \frac{T_{hs} - T_{air,av}}{R_{hs}} \quad (2)$$

Where

$$T_{air,av} = \frac{T_{air,out} + T_{air,in}}{2} \quad (3)$$

Using the mean air temperature is an assumption that is valid for relatively short heat sinks. When compact heat exchangers are calculated, the logarithmic mean air temperature is used. $\dot{m}$ is the air mass flow rate in kg/s.

The above equations show that

- When the air flow through the heat sink decreases, this results in an increase in the average air temperature. This in turn increases the heat sink base temperature. And additionally, the thermal resistance of the heat sink will also increase. The net result is a higher heat sink base temperature.
- The increase in heat sink thermal resistance with decrease in flow rate will be shown in later in this article.
- The inlet air temperature relates strongly with the heat sink base temperature. For example, if there is recirculation of air in a product, the inlet air temperature is not the ambient air temperature. The inlet air temperature of the heat sink is therefore higher, which also results in a higher heat sink base temperature.
- If there is no air flow around the heat sink, energy cannot be transferred.
- A heat sink is not a device with the "magical ability to absorb heat like a sponge and send it off to a parallel universe".
- Natural convection requires free flow of air over the heat sink. If fins are not aligned vertically, or if pins are too close together to allow sufficient air flow between them, the efficiency of the heat sink will decline.

3.5.2 MATERIAL FOR HEAT SINK

The most common heat sink materials are aluminium alloys. Aluminium alloy 1050A has one of the higher thermal conductivity values at 229 W/m•K [6] but is mechanically soft.

Copper has around twice the conductivity of aluminium, but is three times as dense and, depending on the market, around four to six times more expensive than aluminium. Aluminium can be extruded, but copper cannot. Copper heat sinks are machined and skived. Another method of manufacture is to solder the fins into the heat sink base. Diamond is another heat sink material and its thermal conductivity of 2000 W/m•K exceeds copper five-fold.

3.6 COOLING FAN

The axial-flow fans have blades that force air to move parallel to the shaft about which the blades rotate. Axial fans blow air along the axis of the fan, linearly, hence their name.

Fig 3.9: Axial flow cooling fans

This type of fan is used in a wide variety of applications, ranging from small cooling fans for electronics to the giant fans used in wind tunnels. Axial flow fans are applied for air conditioning and industrial process applications. Standard axial flow fans have diameters from 300-400 mm and work under pressures up to 800 Pa.

3.7 THERMAL GREASE

Thermal grease is primarily used in the electronics and computer industries to assist a heat sink to draw heat away from a semiconductor component such as IC’s.

Thermally conductive paste improves the efficiency of a heat sink by filling air gaps that occur when the imperfectly flat and smooth surface of a heat generating component is pressed against the similar surface of a heat sink, air being approximately 8000 times less efficient at conducting heat than, for example, aluminum (a common heat sink material). Surface imperfections and departure from perfect flatness inherently arise from limitations in manufacturing technology and range in size from visible and tactile flaws such as machining marks or casting irregularities to sub-microscopic ones not visible to the naked eye. Thermal conductivity and "conformability" (i.e., the ability of the material to conform to irregular surfaces) are the important characteristics of thermal grease.

In compounds containing suspended particles, the properties of the fluid may well be the most important. As seen by the thermal conductivity measures above, the conductivity is closer to that of the fluid components rather than the ceramic or metal components. Other properties of fluid components that are important for thermal grease might be:

- How well it fills the gaps and conforms to both the components and the heat sink's uneven surfaces.
- How well it adheres to those surfaces
- How well it maintains its consistency over the required temperature range
- How well it resists drying out or flaking over time
- Whether it degrades with oxidation or breaks down over time

The compound must have a suitable consistency to apply easily and remove all excess to leave only the minimum needed.

THERMAL CONDUCTIVITES

For comparison, the approximate thermal conductivities of various materials relevant to heatsinks in W/mK are:

- Air 0.034
- Thermal grease about 0.5 to 10

- Unbranded grease typically 0.8; some silver-and graphite-based greases claim about 9
- Aluminium oxide (surface layer on aluminium) 35
- Steel About 40, varies for different types
- Aluminium 220
- Copper 390
- Silver 420

These are bulk thermal conductivities; the thermal resistance of a particular interface (e.g., a CPU, a thin layer of compound, and a heatsink) is given by the thermal resistance, the temperature rise caused by dissipating 1 W, in K/W or, equivalently, °C/W.

3.8 COOLING BOX

In this design of the thermoelectric refrigerator we make a cooling of metal aluminum alloy because the of the metal has the following properties.

Aluminum alloys

Aluminum alloys are alloys in which aluminum (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al-Si, where the high levels of silicon (4.0% to 13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required.

Alloys composed mostly of the two lightweight metals aluminium and magnesium have been very important in aerospace manufacturing since somewhat before 1940. Aluminium-magnesium alloys are both lighter than other aluminium alloys and much less flammable than alloys that contain a very high percentage of magnesium.

Aluminium alloy surfaces will keep their apparent shine in a dry environment due to the formation of a clear, protective layer of aluminium oxide. In a wet environment, galvanic corrosion can occur when an aluminium alloy is placed in electrical contact with other metals with more negative corrosion potentials than aluminium.

Aluminium alloy compositions are registered with The Aluminum Association. Many organizations publish more specific standards for the manufacture of aluminium alloy, including the Society of Automotive Engineers standards organization, specifically its aerospace standards subgroups, and ASTM International.

3.9 DIGITAL THERMOMETER

THERMOCOUPLE

A thermocouple is a sensor for measuring temperature. It consists of two dissimilar metals, joined together at one end. When the junction of the two metals is heated or cooled a voltage is produced that can be correlated back to the temperature

A thermocouple is available in different combinations of metals or calibrations. The four most common calibrations are J, K, T and E. There are high temperature calibrations R, S, C and G,B. Each calibration has a different temperature range and environment, although the maximum temperature varies with the diameter of the wire used in the thermocouple. Although the thermocouple calibration dictates the temperature range, the maximum range is also limited by the diameter of the thermocouple wire. That is, a very thin thermocouple may not reach the full temperature range. The table includes international color codes for thermocouple alloys, temperature range and limits of error for almost every kind of thermocouple.

Because a thermocouple measures in wide temperature ranges and can be relatively rugged, thermocouples are very often used in industry. The following criteria are used in selecting a thermocouple:

- Temperature range
- Chemical resistance of the thermocouple or sheath material
- Abrasion and vibration resistance

- Installation requirements (may need to be compatible with existing equipment; existing holes may determine probe diameter)

Sheathed thermocouple probes are available with one of three junction types: grounded, ungrounded or exposed (see graphic below:"Thermocouple Tip Styles"). At the tip of a grounded junction probe, the thermocouple wires are physically attached to the inside of the probe wall. This results in good heat transfer from the outside, through the probe wall to the thermocouple junction. In an ungrounded probe, the thermocouple junction is detached from the probe wall. Response time is slower than the grounded style, but the ungrounded offers electrical isolation.

The thermocouple in the exposed junction style protrudes out of the tip of the sheath and is exposed to the surrounding environment. This type offers the best response time, but is limited in use to dry, noncorrosive and non-pressurized applications. A time constant has been defined as the time required by a sensor to reach 63.2% of a step change in temperature under a specified set of conditions. Five time constants are required for the sensor to approach 100% of the step change value. An exposed junction thermocouple is the fastest responding. Also, the smaller the probe sheath diameter, the faster the response, but the maximum temperature may be lower. Be aware, however, that sometimes the probe sheath cannot withstand the full temperature range of the thermocouple type.

Table 2: Specifications of Thermocouple

Material	**Maximum Temperature**	**Application Atmosphere**			
		Oxidizing	Hydrogen	Vacuum	Inert
304 SS	900°C (1650°F)	Very Good	Good	Very Good	Very Good
Inconel 600	1148°C (2100°F)	Very Good	Good	Very Good	Very Good

A thermocouple probe consists of thermocouple wire housed inside a metallic tube. The wall of the tube is referred to as the sheath of the probe. Common sheath materials include stainless steel and Inconel. Inconel supports higher temperature ranges than stainless steel, however, stainless steel is often preferred because of its broad chemical compatibility. For very high temperatures, other exotic sheath materials are also available. View our line of high temperature exotic thermocouple probes. The tip of the thermocouple probe is available in three different styles. Grounded, ungrounded and exposed. With a grounded tip the thermocouple is in contact with the sheath wall. A grounded junction provides a fast response time but it is most susceptible to electrical ground loops. In ungrounded junctions, the thermocouple is separated from the sheath wall by a layer of insulation. The tip of the thermocouple protrudes outside the sheath wall with an exposed junction. Exposed junction thermocouples are best suited for air measurement.

3.10 VOLTMETER AND AMMETER

3.10.1 VOLTMETER

A **voltmeter** is an instrument used for measuring electrical potential difference between two points in an electric circuit.

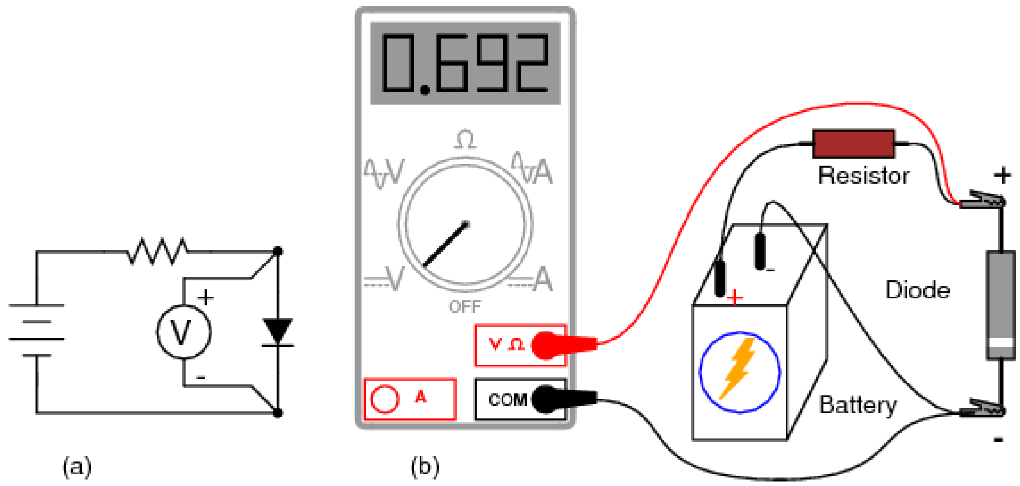

Fig 3.10: circuit of voltmeter

Technically specified, all types of voltmeters are Ammeters because they measure current rather than the voltage. A voltmeter measures voltage only when current is transmitted in a circuit through a resistance. Due to this reason, voltmeters are sometimes referred to as high resistance Ammeters too. They also measure differences of electric potential in volts or units that are fractions or multiples of volts.

WORKING PRINCIPLE OF VOLTMETER:

A Voltmeter can be called a versatile instrument because it measures not only voltage but also current and resistance. It can measure voltages of both types of electric currents- direct current (DC) or alternating electric current (AC). A typical voltmeter scale is graduated in volts, millivolts (1/1000 volt), or kilovolts (1,000 volts). A laboratory standard voltmeter instrument employs electromechanical mechanism for functioning and typically covers ranges within 1000 - 3000 volts (V).

- The voltmeter measures voltage by passing current through a resistance.
- It is designed in such a way so as to offer minimum disturbance to the circuit. This is made possible by using a sensitive ammeter in series with a high resistance.
- The moving coil galvanometer is a type of voltmeter working on this principle.
- The sensitivity of a voltmeter is usually specified in ohms/volt.

3.10.2 AMMETER

An ammeter is a measuring instrument used to measure the electric current in a circuit. Electric currents are measured in amperes (A), hence the name. Instruments used to measure smaller currents, in the mill ampere or microampere range, are designated as milliammeters or microammeters. Early ammeters were laboratory instruments which relied on the Earth's magnetic field for operation. By the late 19th century, improved instruments were designed which could be mounted in any position and allowed accurate measurements in electric power systems.

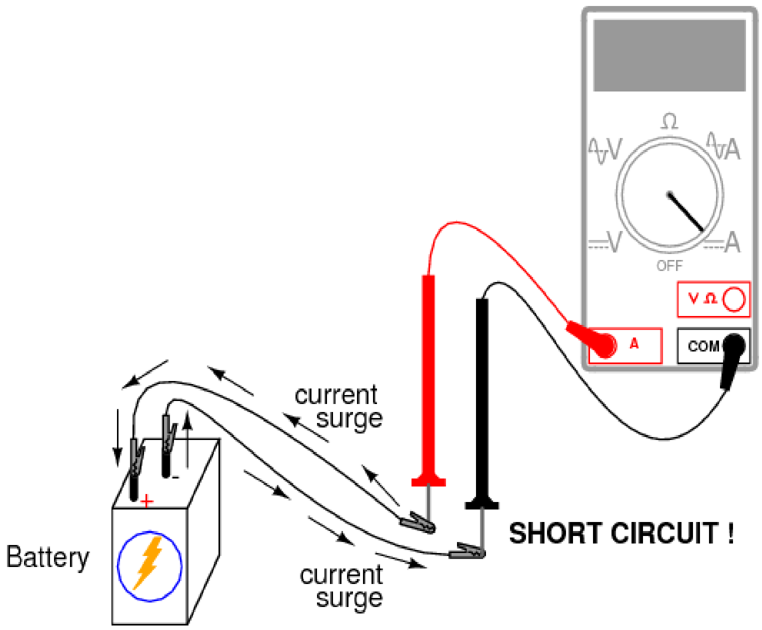

Fig3.11: circuit of ammeter

AMMETER WORKING:

An ammeter works by measuring the voltage dropped across the shunt resistor. For measuring the current flowing in a particular closed circuit, the circuit is first broken and the ammeter is connected in series. When the circuit is reactivated, current flows through the ammeters shunt resistor which causes a voltage drop across the resistor. This voltage drop is then displayed on a voltmeter that is calibrated in amps. If the amount of current is unknown, a fuse is used in series with the shunt resistor. This protects the shunt resistor from getting damaged if the current range is exceeded. An ammeter set to its highest current range that progressively moves down the scale until the proper range is found is safe to work with

Experienced and careful ammeter manufacturers make ideal ammeters having zero input impedance. Ammeters are always placed in series with the circuit to be measured. Therefore an ammeter has to have a low input impedance so that there is minimal effect on the circuit under examination.

CHAPTER-4

EXPERIMENTATION SETUP UP

4.1 SETUP OF THERMOELECTRIC REFRIGERATOR

The major components of the thermoelectric refrigerator include thermoelectric module, aluminum tin, play wood pads, finned surface (or heat sink), and the cooling fan. In this study, single thermoelectric module was used in the design of the refrigerator.

A battery, which stores electricity the form of chemical energy. The module and fan is connected to the battery. The entire set up is assembled in a wooden box with nuts and bolts. The module is placed such that hot side faces the heat sink and a spacer block is placed on the cold side of the module by applying thermal grease. The fan is studded to the heat sink to reject the extra heat. A aluminum container of diameter 12 cm and height of 11 cm is insulated by glass wool. Cooling transfers from module to spacer block and container. for measuring the temperature in the container a thermo couple is connected to digital meter.

The components are connected together intesting the operation of the thermoelectric module. The red wire of the thermoelectric module is connected with the positive power supply (i.e., solar cells) and the black wire of the module is connected with the negative power supply. Due to this method of wire connection, the lower surface of the thermoelectric module became the hot side of the module, while the other side became the cold side of the thermoelectric module. The cold side of the thermoelectric module is needed to be set inside the refrigerator and the hot side to be set outside. The temperatures of the hot and cold sides of the thermoelectric module were measured by thermocouple wires which were connected to the sides of the module. One end of the thermocouples was connected to the hot side of the module whereas the other end was connected to the cold side. The thermocouple was connected to a data logger so the electric current was converted and recorded in temperature units. The hot side of the thermoelectric module was attached to the heat sink whereas the cold side of the thermoelectric module was used to cool the refrigerator cabinet. The heat sink was attached to the hot side of the thermoelectric module to release heat more efficiently out into the atmosphere. The back side of the heat sink was connected with the fan that was used mainly to help in rejecting the extra heat out into the atmosphere.

It can be seen that the temperature of the cold side of the thermoelectric module will decrease and the temperature of the hot side of the thermoelectric module will increase.

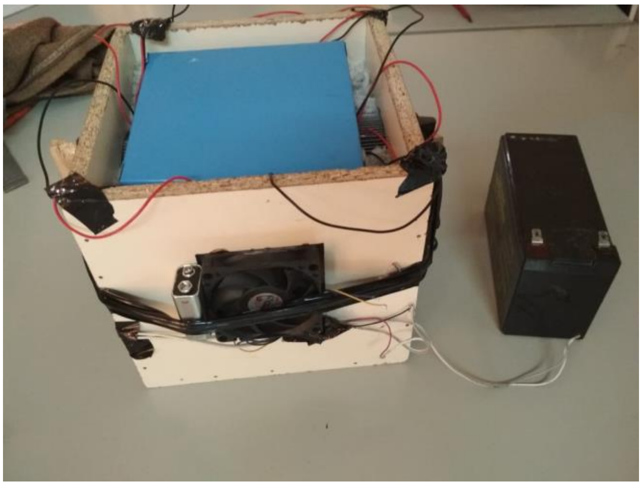

Fig4.1: Cooling Box

4.2 EXPERIMENTATION

4.2.1 EXPERIMENT FOR MINIMUM TEMPERATURE

In this experiment the container is filled with water,. Initially the room temperature is 33^0 C. Then the connections are made and switched on for every 10 minutes of time interval .we recorded the temperature difference through thermo couple which is inserted in to the container which is connected to data card ,we conducted this experiment for 70 minutes finally we got temperature of water as 11^0 C.

CHAPTER-5

RESULTS AND DISCUSSION

5.1 RESULTS

Table 3: Results obtained for minimum temperature

S. No	Variation of water Temperature (^{o}c)	Starting time in (min)	Temperature difference for 10min
1	33	00	0
2	26	10	7
3	22	20	4
4	19	30	3
5	16	40	3
6	14	50	2
7	12	60	2
8	11	70	1

Total time taken to reach 11^0c is 70 min

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